J. MATER. RES. TECHNOL. 2013;**2(1)**:48-51

jmr&t Journal of Materials Research and Technology
www.jmrt.com.br

Original Article

Creep behavior study at 500 °C of laser nitrided Ti-6Al-4V alloy

Adriano Gonçalves dos Reis[a,], Danieli Aparecida Pereira Reis[b], Carlos de Moura Neto[a], Miguel Justino Ribeiro Barboza[c], Francisco Piorino Neto[d], Javier Onõro[e]*

[a]*Instituto Tecnológico de Aeronáutica (ITA), São José dos Campos, SP, Brazil*
[b]*Universidade Federal de São Paulo (Unifesp), São José dos Campos, SP, Brazil*
[c]*Escola de Engenharia de Lorena (EEL/DEMAR/USP), Lorena, SP, Brazil*
[d]*Instituto de Aeronáutica e Espaço (IAE/DCTA), São José dos Campos, SP, Brazil*
[e]*Universidad Politécnica de Madrid (UPM), Madrid, Spain*

ARTICLE INFO

Article history:
Received 22 October 2012
Accepted 20 November 2012

Keywords:
Creep
Ti-6Al-4V
Laser treatment
Nitriding

ABSTRACT

Titanium and its alloys are excellent for applications in structural components submitted to high temperatures owing to their high strength to weight ratio, good corrosion resistance and metallurgical stability. However, the affinity by oxygen is one of main factors that limit its application as structural material at high temperatures. The objective of this study was to estimate the influence of laser treatment on the creep of the Ti-6Al-4V alloy. Constant load creep tests were conducted with Ti-6Al-4V alloy at 500 °C. The creep tests were conducted on a standard creep machine at stress of 319 MPa to 520 MPa. Samples with a gage length of 18.5 mm and a diameter of 3 mm were used for all tests. When the Ti-6Al-4V was tested the effect of the oxidation was smaller and the behavior of the creep curves showed that the life time was better. There was a decreasing of ductility of material (final strain) and life time was increased. Occurred a decreasing of steady state creep in function of the reduction of oxidation process, showing that for the Ti-6Al-4V alloy their life time was strongly affected by the superficial treatment that was submitted because the oxidation suffered by the material.

1. Introduction

Development of alloys to increase creep strength, so permitting the use of higher turbine entry temperatures, has resulted in a general reduction in chromium and increase in aluminum content of nickel superalloys. This has had relatively little effect on high-temperature oxidation resistance, but a very significant adverse effect on corrosion resistance in the lower temperature range in salt-contaminated environments. Such environments are experienced by aircraft operating between airfields with approaches low over the sea with relatively short sector times. Improvements in aero gas turbine performance in terms of power, efficiency and weight have necessitated the use of high specific-strength, low-density materials [1,2].

*Corresponding author.
E-mail address: areis@ita.br (A.G. Reis).

 http://dx.doi.org/10.1016/j.jmrt.2013.03.011

One of the major factors limiting the life of titanium alloys in service is their degradation due to gaseous environments, in particular, the one containing oxygen, especially at elevated temperatures, during the long term use [3]. The sensitivity of titanium alloys to high temperature exposure is a well-known phenomenon. When titanium alloys are heated to temperatures above approximately 800 °C, oxygen, hydrogen and nitrogen penetrate into them. The penetration of the above elements is thought to be undesirable because it increases hardness and brittleness while decreasing the toughness of the alloy [4]. Interaction of titanium alloys with oxygen not only causes loss of the material by formation of oxides, but also causes embrittlement in the subsurface zone of the component due to oxygen enrichment [3].

Titanium alloys is one of the most technologically important materials in the aeronautic and aerospace field for its high strength and lightweight. However, this material does not possess satisfactory tribological property. For this reason, surface strengthening of titanium alloys has attracted much attention [5].

Laser oxidation or nitridation of titanium surfaces are interesting for local hardening and improvement of wear resistance. It is known that melting of the surface layer to enhance the chemical reactions, avoiding significant vaporization and particulates removal, represents the main requirement in direct laser surface oxidation or nitridation of metallic targets in controlled reactive atmospheres [6].

Titanium nitride thin films present interest for applications in technological areas due to their excellent hardness, wear and corrosion resistance, high melting point, chemical inertness, as well as high electrical conductivity. Titanium nitride thin films on Ti or Ti alloy targets are usually obtained by thermal or plasma nitriding and have a good adherence to the metal. The use of laser radiation for nitriding w1-5× is an interesting alternative because of the orders of magnitude higher reaction rates as compared to conventional techniques. In addition, in case of short focused laser pulses, the reduced heat-affected zones both in lateral dimensions and depth ensure the accurate spatial control of the process, i.e. the change of the surface properties of the irradiated area without affecting the bulk. According to the equilibrium phase diagram of the Ti-N system, several crystalline phases can exist w6×. The cubic-face-centered d-TiN (with a nitrogen percentage above 30%) is the most usual titanium nitride phase. The hexagonal a-Ti$(N)_x$ phase has less than 25% nitrogen located interstitially in the hexagonal a-Ti phase lattice. Moreover, in a restricted nitrogen concentration range, between 30% and 40%, other phases may be encountered: tetragonal d9-Ti2N and -Ti2N w6.7×. In general, TiNx thin films with low nitrogen concentration consist of a mixture of these crystalline phases w7-10×. Some authors have claimed that films containing tetragonal Ti_2N phases have better wear and corrosion resistance than those consisting of pure cubic d-TiN w9,10×. Also, in some studies it has been claimed that the hardness of the films increases with the increasing content of Ti2N w7-10×. However, the synthesis of pure tetragonal Ti_2N films was difficult, since the phase development takes place in a restricted domain of adequate processing conditions [7].

The aim of the present study was to measure the influence of the laser treatment Nd:YAG for oxidation protection on creep of the Ti-6Al-4V alloy. A substantial part of the creep research has been devoted to Ti-6Al-4V due to its industrial and technological importance.

2. Experimental procedures

The chosen material for the present study was hot-forged 12.7 mm diameter rod of commercial Ti-6Al-4V alloy with the same specifications as published by ASTM [8]. The microstructure (Fig. 1) consists of equiaxed α grains with average size about 10 μm. The transformed b phase is present in the α grain boundaries [9]. Tensile testing was performed at 500 °C in air according to ASTM standard E 21 specification [10]. The tensile properties are summarized in Table 1 namely, 0.2% yield stress (YS), ultimate tensile stress (UTS), elongation (EL) and reduction of area (RA). The Ti-6Al-4V laser treated

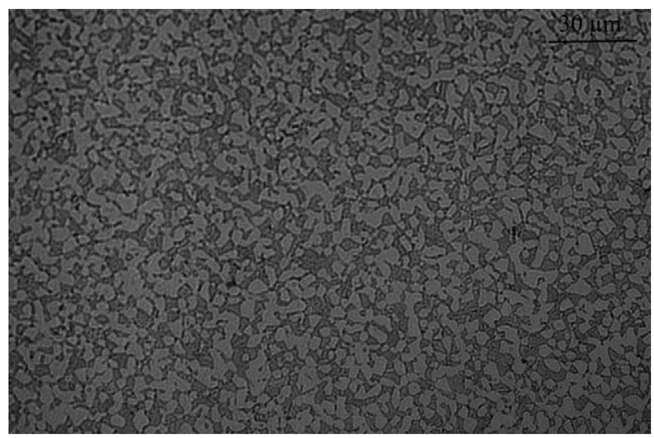

Fig. 1 – Micrograph of Ti-6Al-4V alloy as-received.

Table 1 – Tensile properties of Ti-6Al-4V alloy.

T (°C)	YS (MPa)	UTS (MPa)	EL (%)	RA (%)
500	521	638	30	73.6

EL: elongation; RA: reduction of area; T: temperature; UTS: ultimate tensile stress; YS: yield stress.

Fig. 2 – Ti-6Al-4V coated sample.

Table 2 – Laser treatment parameters.

Parameters	Nd-YAG Laser
Power	2.1 J
Laser scanning speed	10 mm/s
Environment	Air + 40% N + 60% Ar
Nitrogen / Argon Feed	12.5 / 12.5 L/min
Distance between focusing lens-target	89 mm
Diameter laser spot	7 mm
Diameter central zone	2 mm
Incident laser intensity	3.1×10^9 W/cm^2
Distribution	Gaussian

alloy is shown in Fig. 2. The initial creep stress levels were determined from the elevated temperature tensile properties given in Table 1. The Nd:YAG laser treatment parameters used are presented in Table 2, it was used ROFIN DY 033 laser and Talymap Silver 4.0 software. Constant load creep tests were conducted with Ti-6Al-4V alloy at 500 °C. The creep tests were conducted on a standard creep machine at stress of 319 MPa to 520 MPa. Samples with a gauge length of 18.5 mm and a diameter of 3 mm were used for all tests. The creep tests were performed according to ASTM E139 standard [11].

3. Results

Representative creep curves of Ti-6Al-4V laser nitrided are showed in Figs. 3 to 5.

Results from the creep tests at 500 °C are summarized in Table 3, which shows the values of stress (σ), primary creep time (t_p), secondary creep rate ($\dot{\varepsilon}_s$), final creep time (t_f), final strain (ε_f) and reduction of area (RA).

Fig. 6 shows the stress dependence of the primary creep rate for Ti-6Al-4V laser nitrided and without treatment (ST).

Fig. 7 shows the stress dependence of the steady-state creep rate for Ti-6Al-4V laser nitrided and without treatment (ST).

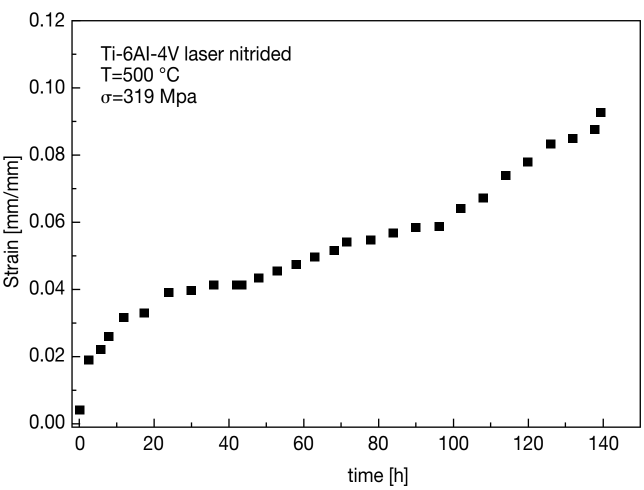

Fig. 3 – Creep curve at 500 °C and 319 MPa of Ti-6Al-4V laser nitrided.

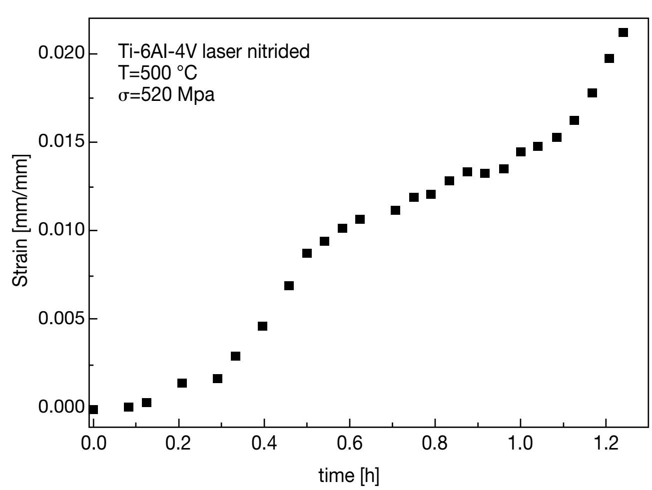

Fig. 5 – Creep curve at 500 °C and 520 MPa of Ti-6Al-4V laser nitrided.

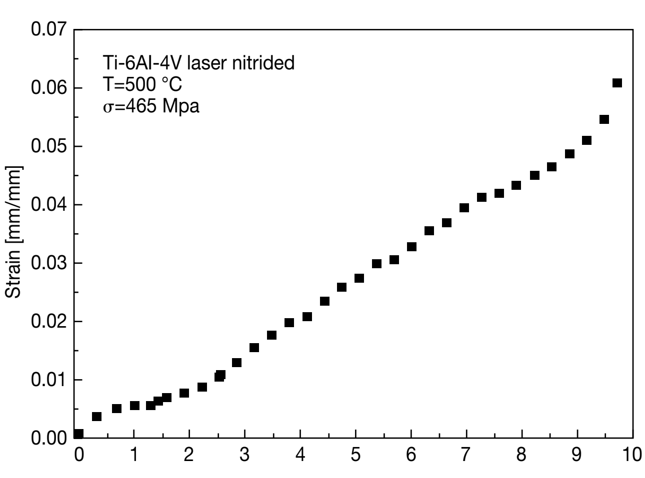

Fig. 4 – Creep curve at 500 °C and 465 MPa of Ti-6Al-4V laser nitrided.

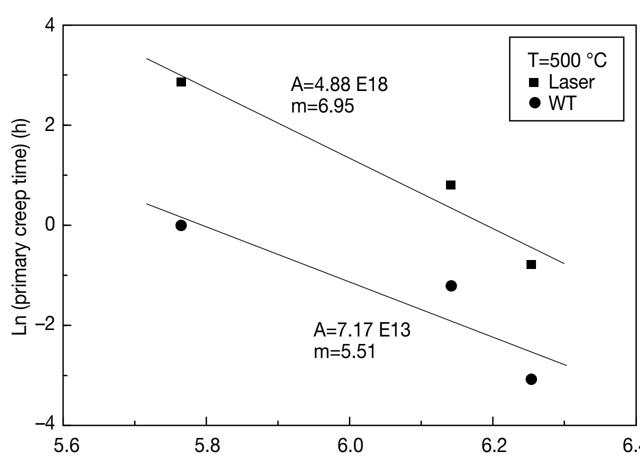

Fig. 6 – Stress dependence of primary creep rate at 500 °C.

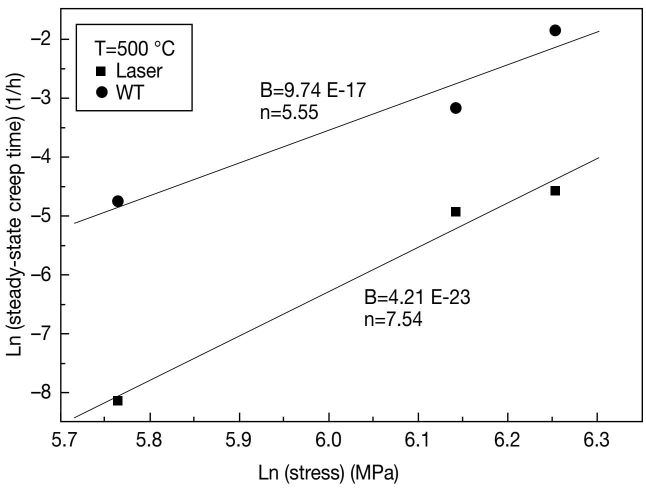

Fig. 7 – Stress dependence of steady state creep rate at 500 °C.

4. Discussions

Figs. 3 to 5 show that most of the creep life of this alloy is dominated by a constant creep rate that is thought to be associated with a stable dislocation configuration due to recovery and hardening process [12-14]. The higher creep resistance of Ti-6Al-4V is observed in laser treated samples in all cases.

The reduction of the steady-state creep rate (Table 3) demonstrates that the higher creep resistance of Ti-6Al-4V is observed in laser treated samples. This fact is related to the hardening superficial formed in Ti-6Al-4V alloy by the laser treatment. It is a well known fact that hard surface and interstitial solid solutions increase the creep resistance of certain alloys. The hardening superficial during creep tests, increases rupture life. It is possible that controlled penetration of oxygen into the alloy Ti-6Al-4V could increase its creep resistance without seriously altering its ductility [4].

5. Conclusions

Constant load creep tests were conducted with Ti-6Al-4V alloy at 600 °C and stress of 319 MPa to 520 MPa. When the Ti-6Al-4V laser treated alloy was tested the effect of the oxidation was smaller and the behavior of the creep curves showed that the life time was better. There was an increasing of life time. Occurred a decreasing of steady state creep in function of the reduction of oxidation process, showing that for the Ti-6Al-4V alloy their life time was strongly affected by the superficial treatment that was submitted because the oxidation suffered by the material.

Acknowledgments

Fapesp, Capes and CNPq for financial support.

REFERENCES

[1] Meetham GW. Use of protective coatings in aero gas turbine engines. Mater Sci Technol. 1986;2:290-4.
[2] Gurrappa I, Gogia AK. High performance coatings for titanium alloys to protect against oxidation. Surf Coat Technol. 2001;139:216-21.
[3] Sai Srinadh KV, Singh KV. Oxidation behaviour of the near ⊠-titanium alloy IMI 834. Bull Mater Sci. 2004;27:347-54.
[4] Rosen A, Rottem A. The effect of high temperature exposure on the creep resistance of Ti-6Al-4V alloy. Mater Sci Eng. 1976;22:23-9.
[5] Chen X, Wu G, Wang R, et al. Laser nitriding of titanium alloy in the atmosphere environment. Surf Coat Technol. 2007;201: 4843-6.
[6] György E, Mihailescu IN, Serra P, Pérez del Pino A, Morenza JL. Single pulse Nd:YAG laser irradiation of titanium: Influence of laser intensity on surface morphology. Surf Coat Technol. 2001;154:63-7.
[7] György E, Serra P, Pérez del Pino A, Morenza JL. Depth profiling characterization of the surface layer obtained by pulsed Nd:YAG laser irradiation of titanium in nitrogen. Surf Coat Technol. 2003;173:265-70.
[8] Howard EB, Timothy LG. Materials Testing. In: Metals handbook. Desk edition. Ohio: ASM International; 1985.
[9] Lee D, Kim S, Lee S, Lee CS. Effects of microstructural morphology on quasi-static and dynamic deformation behavior of Ti-6Al-4V alloy. Metall Mater Trans A. 2001;32:315-24.
[10] Annual book of ASTM standards. In: American Society of Testing and Materials. Standard test methods for elevated temperature tension tests of metallic materials. Philadelphia: ASTM International; 1995. p. 129-36.
[11] Annual book of ASTM standards. In: American Society of Testing and Materials. Standard practice for conducting creep, creep-rupture and stress-rupture tests of metallic materials. Philadelphia: ASTM International; 1995. p. 257-67.
[12] Dyson BF, Mclean M. Creep deformation of engineering alloys: Developments from physical modeling. ISIJ Int. 1990; 30:802-11.
[13] Barboza MJR, Moura Neto C, Silva CRM. Creep mechanisms and physical modeling for Ti-6Al-4V. Mater Sci Eng A. 2004; 369:201.
[14] Reis DAP, Silva CRM, Nono MCA, Barboza MJR, Piorino Neto F, Perez EAC. Effect of environment on the creep behavior of the Ti-6Al-4V alloy. Mater Sci Eng A. 2005;399:276-80.

Table 3 – Creep data at 500 °C.

Temperature (°C)	Treatment	σ (MPa)	t_p (h)	$\dot{\varepsilon}_s$ (1/h)	t_f (h)	ε_f (mm/mm)	RA (%)
500	Without treatment	319	1.000	0.0086	11.530	0.2028	51.51
		465	0.300	0.0430	1.917	0.1361	71.56
		520	0.046	0.1596	0.360	0.1301	71.56
	Laser nitrided	319	17.520	0.0003	139.300	0.0926	10.00
		465	2.217	0.0072	9.727	0.0608	12.12
		520	0.460	0.0103	1.238	0.0212	11.92

RA: reduction of area.